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VIGILANT SPIRIT CONTROL STATION (VSCS) “THE FACE OF COUNTER”

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14. ABSTRACT

The basic concept behind the Cooperative Operations in Urban Terrain (COUNTER) program was one of layered sensing involving a small Unmanned Air System (UAS) over an urban area that was capable of dispensing smaller Micro UAS's to fly at lower altitudes and take closer looks at partially obscured targets. This paper focuses on the Vigilant Spirit Control Station user interface that was enhanced to allow one operator to simultaneously control multiple UAS's during COUNTER simulations and flight tests.

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EXECUTIVE SUMMARY

The basic concept behind the Cooperative Operations in Urban Terrain (COUNTER) program was one of layered sensing involving a small Unmanned Air System (UAS) over an urban area that was capable of dispensing smaller Micro UAS's to fly at lower altitudes and take closer looks at partially obscured targets. This paper focuses on the Vigilant Spirit Control Station user interface that was enhanced to allow one operator to simultaneously control multiple UAS's during COUNTER simulations and flight tests. The use of NATO STANAG 4586 for vehicle connectivity is discussed as a way to provide a common interface to heterogeneous UAS's. An overview of the primary interface components is provided including the use of a video mosaic and digital video recorder (DVR) capability to aid an operator in detecting targets while interacting with multiple simultaneous video feeds. Finally, a detailed description is provided of the user interface developed to interact with COUNTER's cooperative control algorithms. These algorithms provided a dynamic mission planning capability that automatically allocated vehicles to targets and generated mission flight plans to enable the vehicles to fly to the targets in an optimized and cooperative manner.

1.0 INTRODUCTION

The basic concept for the Cooperative Operations in Urban Terrain (COUNTER) program was one of layered sensing involving a small Unmanned Air System (UAS) over an urban area that was capable of dispensing smaller Micro UAS's to fly at lower altitudes and take closer looks at partially obscured targets. A typical mission involved one MLB, Inc. Bat-III aircraft and one or more Applied Research Associates (ARA), Inc. Nighthawk aircraft. The Bat-III contained a single gimbaled camera that had limited operator slew and zoom capability. Each Nighthawk had a fixed forward and side looking camera that the operator could switch between as desired.

The focus of the COUNTER research, from the Air Force Research Laboratory (AFRL) Air Vehicles Directorate perspective, was the development and subsequent testing of the dynamic mission planning (DMP) components that generated mission plans enabling multiple vehicles to simultaneously and efficiently survey the targets requested by the operator. In order to effectively test these targets requested by the operator. In order to effectively test these algorithms, COUNTER needed an operator interface that enabled an operator to choose targets, generate vehicle plans, and manage the overall mission of the vehicles. This requirement was perfectly suited for a teaming arrangement with the Human Effectiveness Directorate, Warfighter Interface Division, System Control Interface Branch's Vigilant Spirit (VS) program.

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VS teamed with COUNTER from the early stages utilizing the Vigilant Spirit Control Station (VSCS). VSCS is a multi-UAS control station capability that enables one operator to simultaneously control multiple vehicles. The focus of the research from the Human Effectiveness Directorate perspective was the operator interface components and underlying software architecture required to allow one operator to control multiple vehicles. VSCS was enhanced to meet the unique requirements of COUNTER and provided the interface through which all simulations and flight testing was completed. VSCS became known as the "Face of COUNTER" since operators were able to see the capabilities of COUNTER come to life via VSCS.

2.0 VIGILANT SPIRIT BACKGROUND

To fully understand and appreciate the capabilities VS brought to COUNTER, a short overview of VS's history is in order. The roots of what is currently the VS program go back several years to a research program simply called Operator Vehicle Interface (OVI) [1]. The focus of this somewhat generically named program was the development of interface concepts that allowed one operator to simultaneously control four lethal unmanned air vehicles (UAV's) in the Suppression of Enemy Air Defenses mission. Figure 1 - OVI shows a sample view of the interface.

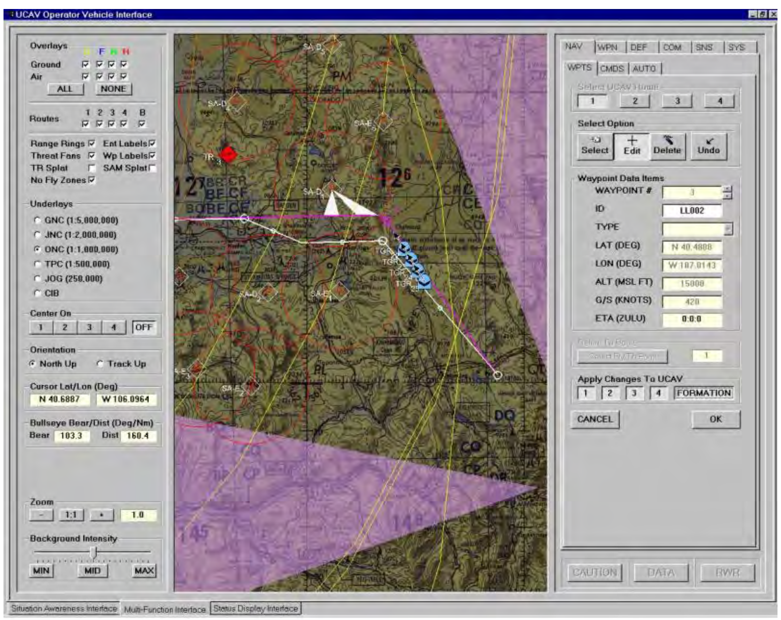

Figure 1 - OVI

During the course of OVI, engineers became members of a UCAV cockpit working group. Concepts were developed and tested that allowed a single operator to manage several vehicles simultaneously; commanding them to perform tasks such as capturing Synthetic Aperture Radar (SAR) imagery and engaging targets.

The OVI follow-on program became what is today known as Vigilant Spirit with its primary product being the Vigilant Spirit Control Station. The lessons learned from various UCAV related projects enabled the VS team to establish numerous collaborations across a broad range of vehicles and mission concepts. These collaborations, many of which are still ongoing at the time of this publication, have proven to be one of the most valuable aspects in the development of VSCS because of the opportunity to explore the operator interface requirements across the various domains. For example, in support of the Long Range Strike program, the VS team enhanced VSCS to support a conceptual unmanned high speed bomber. The vehicle contained a large mixed weapons load and interacted with a DMP capability. For the Automated Aerial Refueling (AAR) program[2], the VSCS gained the addition of formats to enable an operator to manage the refueling of a flight of four UCAV's. The process involves the flight rendezvous with the tanker, the join-up with the tanker, and finally the actual refueling of each vehicle much like the current refueling procedures of a flight of four manned fighters. Numerous other projects have utilized VSCS in various capacities.

Although the types of vehicles and missions planned for COUNTER were at the opposite end of the spectrum from a long range strike vehicle, the flexibility demonstrated by VSCS through the various collaborations indicated it would be well suited for COUNTER. The next several sections will describe in more detail the capabilities added to VSCS to support COUNTER. These additions were made while maintaining a focus on commonality across the various vehicles and missions that VSCS has been involved.

3.0 VIGILANT SPIRIT COMPONENTS OVERVIEW

The overall VSCS system utilized for COUNTER is comprised of several key components as illustrated in Figure 2. This section of the paper provides a brief overview of these components with respect to COUNTER simulation and flight testing. A more detailed operator interface discussion is provided in the next section.

3.1 Vigilant Spirit Software Architecture

The VS software architecture has been designed to support a wide variety of uses. It needs to be able to support a myriad of mission scenarios and vehicle platforms. In addition it must be able to facilitate a multitude of research mechanisms ranging from completely virtual, basic human factors studies, as well as real-life flight tests with all the features of a fielded system. To efficiently author software that meets these goals, a highly flexible software architecture has been developed.

Figure 2 - Vigilant Spirit Components

The VS suite of software has been written entirely using commercial off-the-shelf (COTS) software development tools. Emphasis has been on designing applications to be run on PCs running the Microsoft Windows operating system. The bulk of the VS software is written in the C# programming language. This language choice provides many benefits such as the existence of various rapid application development tools, memory management, and binary compatibility with other languages such as Visual Basic .NET and C++/CLI. A minority of the VS software is written in the native C++ programming language with various calls into the ubiquitously used OpenGL graphics language. An attempt is always made to develop with the latest compilers and development tools and to achieve as much standards-compliance as possible.

Given the wide variety of setups the VSCS must support, it is critical that experiment-specific code modifications are kept to a minimum. For this reason the VS architecture is highly data driven. A large number of data files, used to hold various types of configuration data, are utilized by the VSCS and its supporting software components. Some of the types of data include initial conditions, vehicle characteristics and capabilities, sensor descriptions, network setup, output paths, control station display layouts, and symbol sets. In keeping with conformance to cutting edge commercial standards, these data files are represented almost exclusively using the extensible markup language (XML).

Depending on the type of mission being executed, the mission operator may need any number of tools at his or her disposal to execute the mission successfully. For the VSCS, these tools are provided in the form of a suite of graphical user interface (GUI) components, each providing the operator with the ability to perform a specific task. From the software developer's perspective, these tools are each authored independently. Using the VSCS's underlying data files, the particular subset of these tools that is loaded for a particular mission is completely configurable.

A robust “plug-in” architecture has been developed within the VS software architecture to support the configurable loading of its various GUI components. These components can be authored in a self-contained manner so that providing additional, mission-specific functionality is easy to achieve with minimal development time. Additionally, there are various customization points within VSCS and its supporting components for modules that do not provide a user interface but provide some mission-specific functionality (such as scripting, audio cues, payload modeling, etc).

The underlying framework upon which the VS software is written has been designed for a high level of reusability. Using this basic software engineering principle, developing reusable software enhances the software’s flexibility by shortening the development time required to create new modules. Many fundamental software engineering principles are used including the utilization of some common design patterns. A model-view-controller (MVC) design pattern is commonly used within the framework to separate the underlying data, the user interface components, and the logic required to perform a particular task or respond to a particular event. This allows identical functionality to be displayed to the user in a variety of ways with little code duplication.

3.2 Vehicle Connectivity

Figure 3 shows the COUNTER connectivity diagram utilized for flight testing. The VSCS has been designed to scale across a multitude of vehicle platforms. It is expected to support missions in both real-life and simulation. These variables make the task of making the control station as interoperable as possible very important. The main area where interoperability is implemented in regard to the VSCS is its data link interface (DLI). In particular, the DLI between the control station and the vehicles it is controlling. VSCS utilizes the NATO STANAG 4586 protocol as its DLI.

The aims of STANAG 4586 and the interoperability aims of the VSCS join very nicely. The standard introduces two major software components: the Core UAV Control System (CUCS) and the Vehicle Specific Module (VSM). The CUCS encompasses the human computer interface and in this circumstance is the VSCS. The VSM is a software module that contains the logic needed to translate the 4586 DLI messages into messages that the vehicle understands. The VSM is responsible for translating commands coming from the CUCS to the vehicle and translating reports from the vehicle to the CUCS. It is important to note that the VSM is not the vehicle itself but a bridge connecting the CUCS to the vehicle. The bridge design is one that is familiar in the software engineering discipline and is frequently used to achieve interoperability.

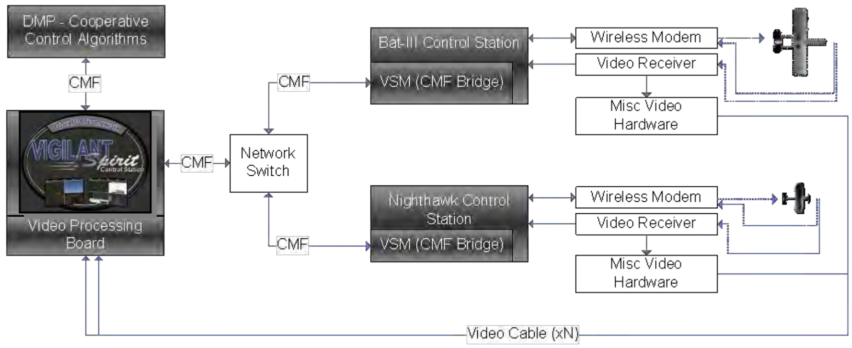

Figure 3 - COUNTER Connectivity Diagram

The 4586 standard describes various components that are used to implement an interoperable UAV control system. The largest segment of the standard is the definition of what is referred to as the Common Message Format (CMF) and the messages that follow this format, making up the data link interface. The messages described in the standard provide the data required for the implementation of a multitude of vehicle commands ranging from navigation to weapons delivery and sensor interaction. The format describes what fields each message has and how to interpret those fields.

For the COUNTER flight tests, both vehicle manufacturers created VSM's that acted as bridges converting VSCS 4586 messages to each vehicle's native message set. This enabled VSCS to communicate with the COUNTER vehicles in the same manner it has for other vehicle integrations. The COUNTER VSM's were tested using the Vigilant Spirit 4586 CMF Toolkit. This toolkit was developed by the VS team to aid with the process of integrating with a new VSM. It consists of a code generator that generates the DLI CMF messages in C#, Java, and C++. The code generator makes it very easy to extend the message set with any required custom messages. To aid in the debugging process during this recurring phase of development, a utility program was written named the Vigilant Spirit 4586 CMF Analyzer. The program was implemented to function similarly to a network packet analyzer but with a focus on receiving/viewing and creating/sending CMF messages.

3.3 Dynamic Mission Planning (DMP)

In the context of the VSCS, DMP is a generic term used to refer to a capability to alter a vehicle's planned course of action in flight. The VSCS focus is not on building DMP capabilities, but rather on how to allow an operator to efficiently interact with them to accomplish mission requirements. The VSCS architecture treats a DMP as a separate process or service that VSCS interacts with. If desired, each different vehicle type could have its own unique DMP capability tuned specifically to its specifications. The location of the DMP is also flexible. In some cases it may be desirable to have the DMP on the vehicle. In other cases, due to processing limitations of the vehicle or communications constraints, it may be more advantageous to place the DMP with the control station.

For COUNTER, the DMP capability consisted of the Cooperative Control Algorithm (CCA) planner, Search Pattern Planner (SPP), and Stochastic Controller (SC)[3]. These capabilities were bundled together in a separate process that ran on the same computer as the VSCS. The VSCS communicated with this process using a set of custom messages that were built to satisfy unique DMP requirements. These messages were built using the VS 4586 CMF Toolkit following the same DLI format as the messages used to communicate with the vehicles. The details of the COUNTER DMP are beyond the scope of this paper.

3.4 Simulation

To effectively test most systems, portions of the environment they operate in need to be simulated. The VSCS development for COUNTER was no different. The overall COUNTER project consisted of three levels of simulation including the Engineering Simulation, the Operational Simulation, and what we are discussing here as the Developmental Simulation. This simulation capability strives to enable the VSCS engineers to conduct their testing as if they were in the field with real aircraft. Almost without exception, the VSCS engineers were not required to build any special capabilities to do lab testing versus flight test. For flight tests, the VSCS lab systems were disconnected from power, network, and video, taken to the field, re-connected and were ready to go. This required our vehicle simulations to communicate in the same manner as flight test vehicles. The vehicles' cameras along with the virtual worlds they were viewing needed to be simulated. While simulation development is not the primary focus of the VS program, it has been a necessity for effective development and testing of the VSCS. The VSCS has been architected to utilize not only VS's limited simulation capability, but also the more sophisticated capabilities of other organizations.

4.0 VSCS USER INTERFACE PRIMARY COMPONENTS OVERVIEW

As the title of the paper indicates and was mentioned in the introduction, "VSCS, The Face of COUNTER" has really been a good catch phrase to illustrate the VSCS's involvement with various projects. The phrase was coined by former COUNTER program manager Captain Nidal Jodeh (AFRL/RBCA). The point was made that much of COUNTER's primary research interest was in the behind the scenes cooperative control algorithms, but how the operator interacted with them was brought to life through what you saw with via the innovative user interfaces developed for the VSCS. This analogy has proven true for VSCS development across numerous projects that the VSCS has been applied to and tends to be true for any interface development work. From the user interface perspective, COUNTER presented the VSCS team with several new challenges that will be highlighted in the next several sections.

The VSCS operator interface incorporates a flexible modular design that can be configured to accommodate several diverse mission requirements. Individual graphical user interface components, or tools, can be included as desired for a particular mission. The VSCS's tool arrangement can be configured to accommodate any particular computer system display capability and resolution. Figure 4 shows a typical VSCS two display configuration (Each 24" diagonal with a 1920 x 1200 pixel resolution) and tool layout used during COUNTER flight tests. This example illustrates a three vehicle configuration involving one Bat-III and two Nighthawk vehicles. The primary tools utilized include the Summary Panel, Tactical Situation Display (TSD), Video Mosaic Tool, and the Video Tool. The VSCS contains other tools, but only the ones used most frequently for COUNTER will be discussed.

Figure 4 - VSCS Typical COUNTER Configuration

4.1 Summary Panel

Along the left edge of the left display is the Summary Panel. The Summary Panel is designed to provide a quick look summary of important information for each aircraft tailored to its current mission phase. An individual pane is provided for each aircraft and a sample is shown in Figure 5. To help the operator quickly distinguish between different aircraft, four unique features are utilized. First is the icon shape in the upper left corner representing the vehicle (Bat-III), second is a unique color (Orange), third is the call sign (BAT-A), and fourth is a unique digit representing the number of aircraft we're controlling (1). These features are consistently used across the various VSCS tools to distinguish between vehicles.

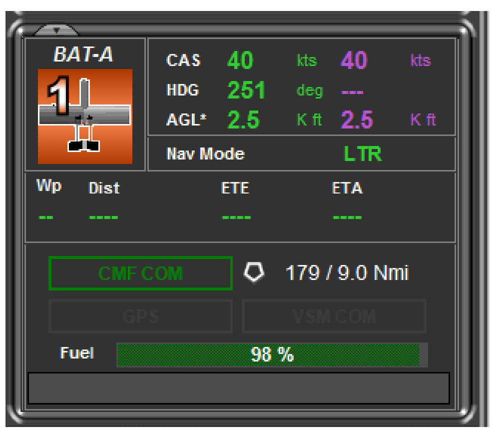

Figure 5 - Summary Panel

4.2 Tactical Situation Display (TSD)

The next major tool available to the operator was referred to as the Tactical Situation Display (TSD). The TSD consists of underlay maps or imagery of an operational area with information overlays. The underlay surface supports standard aviation charts and geo registered imagery. An icon of each vehicle is drawn on the TSD at its proper geographical location and orientation. Other information such as the current vehicle plan, preview plans, sensor footprints, and target locations are also shown. The TSD is the primary situational display used by the

operators to monitor and provide status information for each vehicle. It can be thought of as any standard mapping application but is tailored to facilitate vehicle control. Various options are available for easily slewing the map around and changing the map scale. Other options are also available for turning on or off a choice of overlay items.

The bottom area of the TSD contains a pop-up component called the command tool. This is the area where the operator can control various aspects of the mission and interact with the DMP to create new mission plans. The component can be shown or hidden as desired by the operator but was left up most of the time during COUNTER testing. The primary command tool tabs or pages utilized for COUNTER were Nav, Loiter, Plans, DMP, DMP Search, and Camera.

4.3 Video Mosaic Tool

Located to the right of the TSD, as shown in Figure 4, is the Video Mosaic Tool. This is one of the user controls that was first created and tested in support of COUNTER. This component was created using a COTS software development kit (SDK) and supported only one video source at any particular time. The tool essentially painted the operator a larger view using multiple video frames. A good analogy is taking a deck of cards and fanning them out on a table with each card being a different video frame. This tool provided the operator additional situational awareness and helped to provide a more stabilized view of targets during turbulent conditions.

4.4 Video Tool

The configuration as seen in Figure 4 shows three separate Video Tools stacked along the right edge of the right display. Each Video Tool allows the operator to select an analog video source being transmitted from one of the vehicles currently under VSCS control. Figure 6 allows a closer look at one of the video tools. The control station also provided a Digital Video Recorder (DVR) capability that allowed the operator to scroll back in the video feeds if desired. This capability proved useful when flying low over targets with the Nighthawk. The Nighthawks were typically flown around 22-24 knots which is not very fast, but at 125 feet off the ground, positively identifying targets could be challenging since they were in view for such a short time. With turbulence and video distortions the task became even tougher. The DVR allowed the operator to slide the video back in time and freeze frame on the target to allow a little more time for target identification. The Video Tool DVR contains other functionality similar to that found on home DVR systems. Features such as pause, fast forward, etc. exist and are useful to the target acquisition process, but will not be discussed here.

Figure 6 - Video Tool

5.0 INTERACTING WITH COUNTER ALGORITHMS

As was mentioned in the introduction to this report, the basic concept for the COUNTER program was one of layered sensing involving a small UAS over an urban area that was capable of dispensing smaller micro UAS's to take closer looks at partially obscured targets[4]. This section provides a few examples of an operator using the VSCS to interact with the COUNTER algorithms. These examples are typical of what was done during flight testing to execute a COUNTER test card. The VSCS also provides several convenient methods to allow the operator to easily perform tasks such as configuring loiter parameters and controlling payloads but the discussion of these items is beyond the scope of this paper.

For the example illustrated here, we will assume the operator is in control of a single Bat-III with a call sign BAT-A and two Nighthawks with call signs MAV-A and MAV-B. Each of the vehicles are in predefined circular loiters around different points with an overall VSCS configuration as illustrated in Figure 4. The operator's task is to pick targets and utilize the COUNTER DMP capabilities to generate plans that Nighthawks will fly at low level to view the targets.

Figure 7 shows a TSD with the Command Tool area open along the bottom edge. The Command Tool's DMP tab is colored blue indicating that the DMP Command Tool is the one currently selected. With the DMP Command Tool selected, the next task the operator needs to do is determine which of his available vehicles to use. The vehicle selector control shows that both Nighthawks have been selected. This is indicated by the background of the selector button being filled with the color assigned to the vehicle. Just below the vehicle selector is the payload options area. This shows the list of available payload items that can be used for generating a plan. In this case the only item available is a camera that is shown as selected by the blue background color. Once the vehicles are selected, each one needs to be configured for the desired altitude and speed settings. This is accomplished by selecting the Vehicle Settings option and entering the proper values.

Now that the vehicles are selected and configured, the operator has three options for entering target points. The first way is to monitor one of the vehicle's video feeds and click on a desired location directly in the Video Tool. This causes a target entry to be added to the target list as well as a geo-referenced target point to be added on the TSD. The operator's next option is to select a target point directly from the TSD. This is accomplished by holding down the Shift key, moving the cursor to the desired location over the TSD and clicking the left mouse button. The final way is to enter a point directly by typing in the coordinates using the controls on the DMP Command Tool.

Figure 7 shows six Electro-Optical (EO) or camera targets in the target list that are labeled as EO-5 to EO-10. These target points are also shown on the TSD as grey outlined squares with the same labels. The operator now has the option to constrain the approach angle to a target. In this example, the operator selects target EO-6 and in the constraints area specifies that the vehicle should approach the target from a heading of 090 degrees with a standoff distance of 1000 feet. The enabled constraint is the one with the blue On button selected to the right of the

Figure 7 - Target Selections

constraint values. Up to four constraints can be added to a target. At this point the operator selects the green Request New button to request that plans be generated for each of the selected aircraft using the targets and constraints entered.

Figure 8 shows the TSD with a proposed plan generated by the COUNTER algorithms for both MAV-A and MAV-B. The proposed plans are represented as dashed lines using each vehicle's assigned color. The lines are dashed indicating that they are only proposed plans that have not yet been sent to the vehicle. The DMP Command Tool shows the estimated duration of

each of the plans along with the number of waypoints each contains. The operator is given the option to reject or accept both the plans. Note that the algorithm provided the vehicle to target allocation as well as the optimized plans to visit each target. For this example, the operator accepts the plans which cause them to be sent to each of their respective vehicles. Since the vehicle's navigation mode is set to loiter (LTR), they do not begin flying the plans right away. It is not shown, but the plans show up as dim solid lines on the TSD once the vehicles acknowledge receipt of the plans. The operator selects the NAV Command Tool tab and places both Nighthawk vehicles into waypoint (WPT) mode. At this point each of the vehicle plans show up as brighter solid lines indicating that they are the active plans currently being flown.

Figure 8 - Pending Plans

Figure 9 - Nighthawks Flying Plans

Figure 9 now shows the TSD zoomed in with both Nighthawks well into each of their missions. The TSD shows that the sensor footprint of the Nighthawk with call sign MAV-A is now over one of its targets at the same time the Bat-III is looking at the same target from above. Now that the Nighthawks are flying their low level missions, the operator has several tools at his disposal to aid in seeing the selected targets in the Nighthawk's video. Even though the Nighthawks travel at a slow speed, identifying a specific target can still be a challenging task since the sensor footprint is so small and the vehicle travels over the target area very quickly at low levels. The VSCS has several built in tools to aid with the target identification. The first being the DVR capability mentioned in an earlier section. Figure 10 shows a view of the TSD with the vehicle of interest shown at its current location along with what is called a ghost ship view. The ghost ship is shown with a dashed sensor footprint outline and represents where the vehicle was at some past time. The ghost ship is created whenever the DVR capability is used to view past video. This correlation can be useful when trying to find the section of video when the vehicle was over one of the targets.

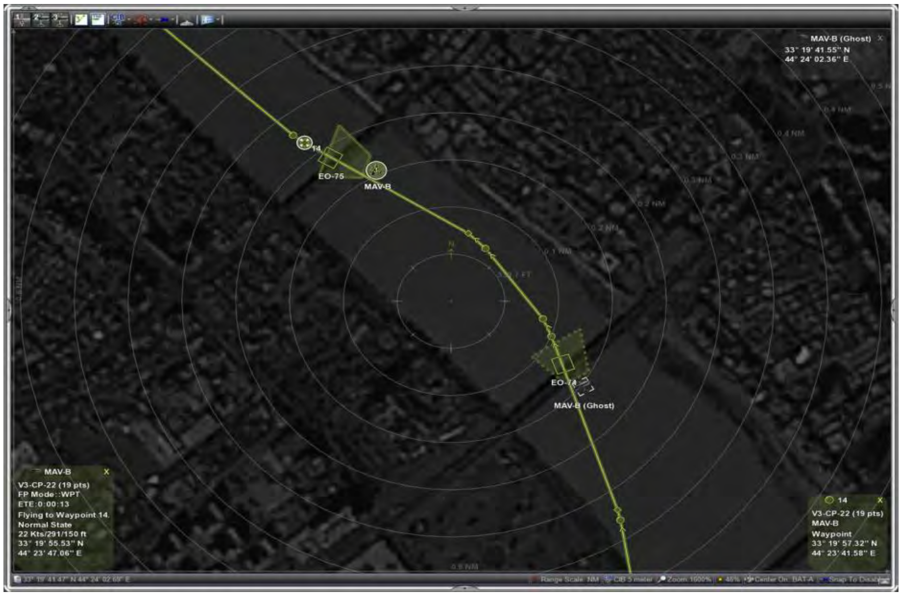

Figure 10 - Ghost Ship

6.0 CONCLUSION

Any successful program draws upon the talents of research individuals across a multitude of disciplines. The combination of the AFRL Air Vehicle Directorate and the Human Effectiveness Directorate proved to be a successful integration of both control law algorithms and human-centered UAS supervisory control. The need for a common UAS ground control station that could be utilized in a research and flight test environment helped to mature the VSCS over the past several years. The VSCS became an integral test bed utilized across a multitude of programs and basic research organizations. The VS team has developed a mature and robust software architecture using state-of-the-art development tools and has incorporated COTS to help reduce costs and enhance functionality.

A key component for making a successful simulation environment has been the use of the NATO STANAG 4586 message set. The VS team recognized the importance for implementing a common standard messaging protocol to effectively communicate to a diverse set of UAS's. The development of the VS STANAG 4586 Common Message Format Toolkit has been integral to the success of allowing a wide variety of vehicle vendors to create VSM's. This has allowed our simulation environment to scale across vehicle platforms and provide both a simulation and flight-test ready system.

The COUNTER program has been an integral facilitator of the many features that have enhanced the situational awareness of the operator-vehicle dynamic. Being the "Face of COUNTER", the VSCS enabled the AFRL Air Vehicles Directorate cooperative control algorithms to be tested in simulation as well as live flight tests. This DMP capability has allowed for further research to be done evaluating the effectiveness of multiple vehicle control in an urban environment. Effective sensor management techniques through the introduction of the

DVR capability and live video mosaicing, has proven to enhance the operator awareness through the use of cooperative vehicle planning. Further research will be conducted looking into adding additional features to the CCA algorithms such as terrain avoidance, weather, airspace management, road network planning, and many others. Search patterns and stochastic controllers will also be evaluated to aid the operator in making decisions during the DMP process and target identification.

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LIST OF ACRONYMS

AAR	Automated Aerial Refueling
ARA	Applied Research Associates
AFRL	Air Force Research Laboratory
CCA	Cooperative Control Algorithm
CMF	Common Message Format
COTS	Commercial Off-The-Shelf
COUNTER	Cooperative Operations in Urban TERrain
CUCS	Core UAV Control Station
DLI	Data Link Interface
DMP	Dynamic Mission Planning
DVR	Digital Video Recorder
EO	Electro-Optical
GUI	Graphical User Interface
MVC	Model View Controller
OVI	Operator Vehicle Interface
SAR	Synthetic Aperture Radar
SC	Stochastic Controller
SDK	Software Development Kit
SPP	Search Pattern Planner
TSD	Tactical Situation Display
UAS	Unmanned Air System
UAV	Unmanned Air Vehicle
UCAV	Unmanned Combat Air Vehicle
VS	Vigilant Spirit
VSCS	Vigilant Spirit Control Station
VSM	Vehicle Specific Module
XML	Extensible Markup Language